

## Variations of Calcium Carbonate, Organic Carbon and Their Isotopic Compositions in Surface Sediments of the East China Sea

DAVID D. SHEU<sup>1</sup>, WEN-CHEN JOU<sup>1</sup>, MING-JUE CHEN<sup>1</sup>, WAY-YUAN LEE<sup>1</sup> and SAULWOOD LIN<sup>2</sup>

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### ABSTRACT

This study analyzes the carbonate and organic carbon contents and their carbon and oxygen isotopic compositions of a total of 58 surface sediment samples from the continental margin of the East China Sea. Additional gas chromatographic (GC) analysis of selected sediment samples was performed to show typical concentration and distribution of n-alkanes in these sediments.

Results show that carbonate contents of sediments in the region are highly variable from 3.0 to 63.1 wt% across the shelf, yet they show an increase toward the south in a lobate distribution between water depths of approximately 90 and 150 m. Except for some data, values of  $\delta^{13}\text{C}$  of carbonates in general vary in a narrow range of  $0 \pm 1\text{‰}$  as compared to those of  $\delta^{18}\text{O}$  that varies considerably over a range from 0 to  $-6\text{‰}$ . Organic carbon concentrations of sediments range from 0.1 to 1.44 wt% and become enriched toward the north.  $\delta^{13}\text{C}$  of organic carbon varies from  $-22.9$  to  $-20.1\text{‰}$  and shows a vague increase (becomes heavier) with increasing distance from the coast. Results from GC analysis reveal that the n-alkane concentrations in sediments can vary up to ten-fold and are predominant with  $\text{C}_{21}$ - $\text{C}_{25}$  compounds.

Cross plots of carbonate and organic carbon concentrations vs. water depths further reveal that sediments of high carbonate content are invariably characteristic of low organic carbon contents and vice versa. Such a contrasting feature can be attributed to the winnowing effect upon sediment accumulation during low stands of sea level. Moreover, carbonates from sediments of high carbonate contents are found to be depleted in  $^{18}\text{O}$ , indicative of a relic origin of the carbonates and likely the associated sediments. The pattern of n-alkane distribution reveals that the sediment mainly consists of organic matter of reworked and/or transported origins. As a consequence, geochemical and stable isotopic characterization of surface sediments in this study supports an episode of relic sedimentation in the East China Sea between the present-day water depths of approximately 90 and 150 m and is thus consistent with previous observations.

(Key words: Calcium carbonate, Organic carbon, Carbon and oxygen isotopes, n-alkanes, the East China Sea)

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<sup>1</sup> Institute of Marine Geology, National Sun Yat-Sen University, Kaohsiung, Taiwan, R.O.C.

<sup>2</sup> Institute of Oceanography, National Taiwan University, Taipei, Taiwan, R.O.C.

## 1. INTRODUCTION

The passive continental margin of the East China Sea, occupying two-thirds of the East China Sea continental margin, is one of the largest continental shelves in the world. Unlike most shelf regions that usually act as a major sink for sediment accumulation, the East China Sea continental shelf has experienced a diversity of sedimentary episodes including non-deposition during low stands of sea level (Emery *et al.*, 1971; DeMaster *et al.*, 1983). The broad shelf becomes increasingly narrow and deep toward the south along the eastern coast off mainland China and has an average water depth of approximately 72 m.

Sediments of different origins and sedimentary properties are presently found to disperse in zonal patterns along isobaths of various depths across the shelf (DeMaster *et al.*, 1983; McKee *et al.*, 1983; Yang and Milliman, 1983; Milliman *et al.*, 1985a and 1985b). The middle shelf is dominated by well-sorted fine/muddy sands and gravel of relic origin and is flanked by silty clays and silty/clayey sands that are derived from the Yangtze and Yellow Rivers and deposited in the inner and outer shelves. Such distribution patterns are further shown by Milliman *et al.* (1985a; 1985b) and Zhu *et al.* (1990) to result from various transport mechanisms interacting in the region.

The study of sediments in the East China Sea continental shelf, therefore, has long been interesting to sedimentologists in the world because sedimentation in this region represents a unique history of complicated sediment accumulation during low stands of sea level which is rarely seen in other shelf regions of the world oceans. Results of the above studies, however, were mainly inferred from sedimentological and mineralogical criteria, with scant attention to other sediment properties that have been shown to be greatly helpful in discerning sediment deposition in continental margins. The objective of this study thus aims to document the geochemical and stable isotopic properties of the surface sediments on the East China Sea continental shelf so that a better characterization of sediment accumulation in the region, especially during low stands of sea level, can be achieved.

## 2. MATERIAL AND METHODS

A total of 58 surface sediment samples analyzed in this study were collected from the continental margin of the East China Sea using box corers aboard the *R/V Ocean Researcher I* and *R/V Vinogradov* (Table 1 and Figure 1). However, it must be pointed out that sampling locations shown in Table 1 were obtained from shipboard GPS records, and their corresponding water depths were found to be inconsistent with those shown in the bathymetric map usually used on shipboard. To eliminate confusion, the discussion of sediment data in this study follows the coring depths reported in the KEEP-MASS cruise report.

Upon return to the laboratory, the top sections of cores were sampled in various thickness and dried in a freeze dryer to a constant weight. After freeze drying, the sample was ground to a powder and stored in vials for later analyses. Total carbon and organic carbon were measured in duplicate using a LECO CS-244 carbon/sulfur analyzer (Boyce and Bode, 1972). Dried sediment samples were split. One aliquot was analyzed for total carbon. The other was digested with 3 N HCl to remove carbonates and then washed thoroughly with distilled water prior to organic carbon determinations. The difference between the two measurements was defined as the inorganic carbon and was reported as the CaCO<sub>3</sub> content. Although the

Table 1. Sampling locations and pertinent coring data of sediments analyzed in this study.

Sample No.	Cruise - Station No.	Latitude (N)	Longitude (E)	Sampling interval (cm)	Water Depth (m)
1	OR293-920722	26°30'	121°20'	0-2	78
2	OR293-920703	25°40'	121°41'	0-2	135
3	OR322-910937	26°15'	122°15'	0-2	100
4	OR322-910935	25°45'	122°45'	0-2	104
5	OR322-910942	26°50'	122°10'	0-2	97
6	OR322-910946	26°10'	122°50'	0-2	108
7	OR322-910948	25°50'	123°11'	0-2	100
8	OR322-910956	26°35'	122°55'	0-2	118
9	OR322-910954	26°15'	123°15'	0-2	126
10	OR322-910952	25°55'	123°35'	0-2	133
11	OR322-910966	26°10'	123°50'	0-2	136
12	OR322-910968	25°50'	124°10'	0-2	194
13	OR322-910960	27°10'	122°50'	0-2	106
14	OR322-910973	26°55'	123°35'	0-2	116
15	OR322-910971	26°35'	123°55'	0-2	134
16	Vinogradov-E1	27°56'	122°37'	0-2	72
17	Vinogradov-E2	27°41'	122°50'	0-2	81
18	Vinogradov-E3	27°29'	123°07'	0-2	103
19	Vinogradov-E4	27°21'	123°23'	0-2	104
20	Vinogradov-E5	27°11'	123°40'	0-2	110
21	Vinogradov-E6	27°00'	124°00'	0-2	120
22	OR293-920977	26°50'	124°10'	0-2	129
23	OR293-920979	26°30'	124°30'	0-2	143
24	Vinogradov-E15	28°25'	123°53'	0-10	79
25	Vinogradov-E14	28°17'	124°10'	0-2	85
26	Vinogradov-E13	28°08'	124°26'	0-2	95
27	Vinogradov-E12	28°01'	124°44'	0-2	104
28	Vinogradov-E11	27°52'	125°00'	0-2	102
29	Vinogradov-E10	27°44'	125°18'	0-2	102
30	Vinogradov-E9	27°36'	125°36'	0-2	113
31	Vinogradov-E8	27°27'	125°51'	0-2	123
32	Vinogradov-E7	27°23'	126°06'	0-2	330
33	Vinogradov-E16	29°44'	124°07'	0-10	60
34	Vinogradov-E18	29°25'	124°39'	0-2	74
35	Vinogradov-E20	29°03'	125°09'	0-2	78
36	Vinogradov-E21	28°54'	125°26'	0-2	102
37	Vinogradov-E22	28°43'	125°41'	0-2	104
38	Vinogradov-E24	28°22'	126°12'	0-2	114
39	Vinogradov-E35	30°40'	124°43'	0-10	53
40	Vinogradov-E33	30°24'	125°08'	0-2	66
41	Vinogradov-E32	30°14'	125°24'	0-2	69
42	Vinogradov-E31	30°04'	125°38'	0-2	64
43	Vinogradov-E30	29°52'	125°55'	0-2	77
44	Vinogradov-E29	29°41'	126°14'	0-2	90
45	Vinogradov-E28	29°32'	126°27'	0-2	100
46	Vinogradov-E26	29°12'	126°58'	0-2	122
47	Vinogradov-E27	29°21'	126°42'	0-2	108
48	Vinogradov-E24a	28°04'	126°41'	0-2	440
49	Vinogradov-E25a	29°06'	127°46'	0-5	1090
50	Vinogradov-E36	32°00'	125°18'	0-2	51
51	Vinogradov-E38	31°38'	125°47'	0-5	60
52	Vinogradov-E39	31°26'	126°03'	0-2	67
53	Vinogradov-E40	31°15'	126°18'	0-2	78
54	Vinogradov-E42	30°53'	126°48'	0-2	96
55	Vinogradov-E43	30°43'	127°00'	0-2	96
56	Vinogradov-E44	30°30'	127°15'	0-2	110
57	Vinogradov-E46	30°09'	127°43'	0-5	228
58	Vinogradov-E46a	29°47'	128°27'	0-6	940

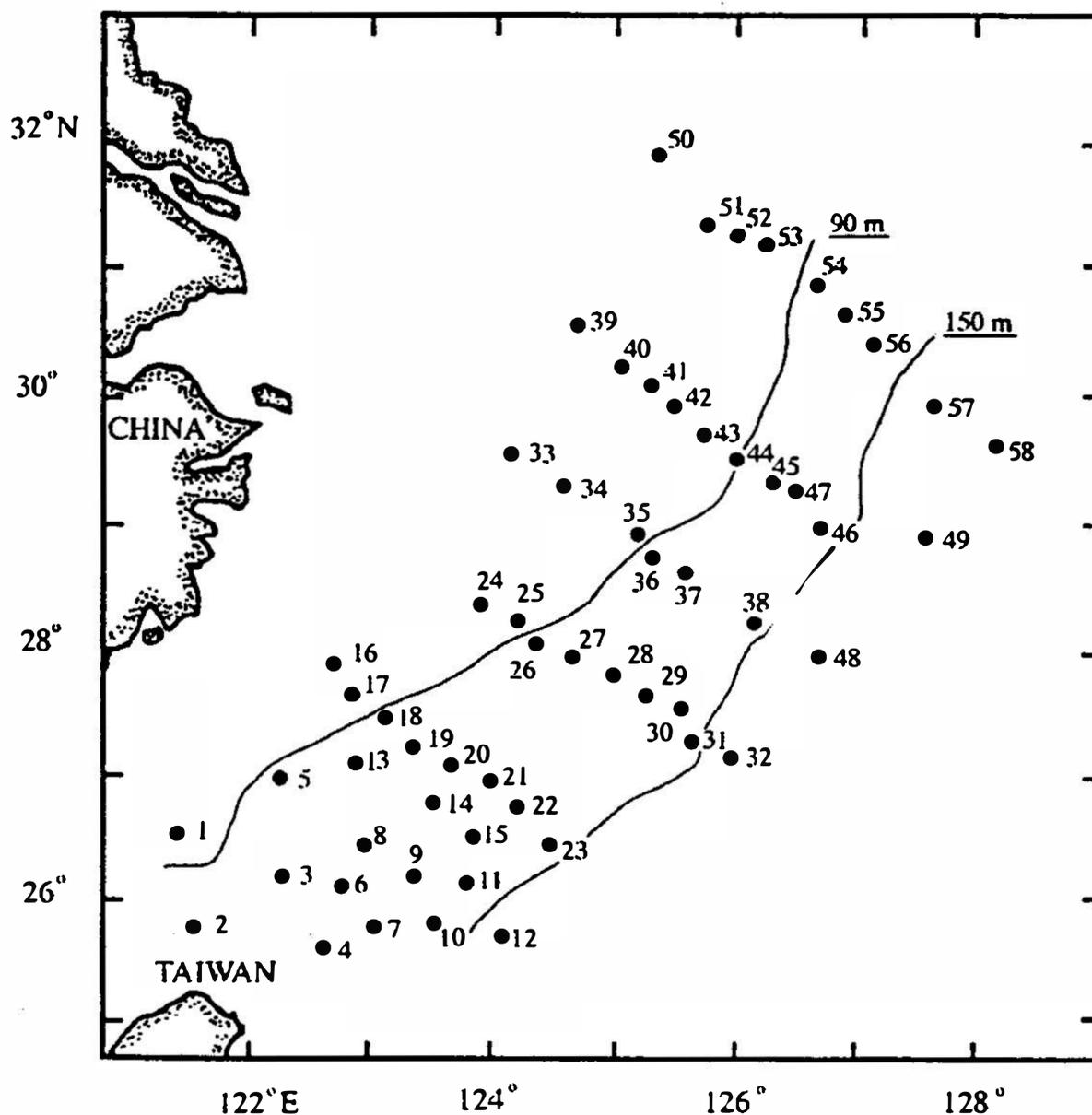


Fig. 1. Sampling locations and study area in the East China Sea continental margin. Bathymetric contour lines of 90 and 150 meters denote approximately the spatial distribution of the relic sediments characterized by this study.

acid pretreatment procedures may cause some loss of organic volatile during organic content analysis in sediments, the amount of this loss is difficult to quantify, and on the other hand, other procedures that have been employed to better improve the measurements are laborious (Heath *et al.*, 1977; van Iperen and Helder, 1985 and references therein). Furthermore, in the evaluations in this study it was found that sediment organic carbon determined by the acid pretreatment method appears to agree fairly well with that measured by combustion techniques, especially when low organic carbon concentration (<0.5 wt%) of sediments is analyzed. The precision of these analyses, based on 10 sets of duplicates of measurements and expressed as 1 standard ( $\sigma$ ) deviation, are  $\pm 0.24\%$  and  $\pm 0.02\%$  for  $\text{CaCO}_3$  and organic carbon, respectively.

Another aliquot of the powdered sediment of approximately 2 gm was transferred into a 20 ml centrifuge tube for the extraction of normal alkanes using a  $\text{CH}_2\text{Cl}_2$  : MeOH (6 ml; 3/1 by volume) mixture. The tube was closed tightly with a teflon-lined, screw-on cap and placed in an ultrasonic vibrator for 15 minutes. The procedures were repeated three times, and the extracts were collected. These extracts were then eluted with appropriate amounts of  $\text{CH}_2\text{Cl}_2$  through a short silica gel column to obtain lipid classes.

Analyses of lipid fractions were performed on a Varian 3400 gas chromatograph (GC) with a high performance septum-equipped temperature programmable injector (SPI) and a flame ionization detector (FID). A fused silica capillary column (DB-1, 60 m long, 0.25

mm i.d.) was used with helium as a carrier gas. The oven temperature was programmed from 35 °C to 235°C at a rate of 10°C/min, to 300°C at 5°C/min and then to 325°C at 1 °C/min. The identification of normal alkanes was furnished with the specific retention time of an external standard of known carbon numbers. Quantization was made using an internal standard that was added to the samples prior to the extraction process. Full procedural blanks were routinely carried out throughout this study to ensure the absence of contamination from solvents. Potential contamination of the aliphatic hydrocarbons from pump oil during freeze drying of sediments was negligible or below the resolution limit of the GC analysis.

The preparation of CO<sub>2</sub> gas from sediment samples for carbon isotopic analyses followed the methods of McCrea (1950) and Craig (1953; 1957). Carbonates of bulk sediments were reacted with 100% H<sub>3</sub>PO<sub>4</sub> to produce CO<sub>2</sub>. No correction for possible contamination from organic CO<sub>2</sub> was made for isotopic measurements in this study because of the low organic carbon contents (generally < 0.5 wt%) in the sediments. The isotopic analysis of contamination-free CO<sub>2</sub> samples is further confirmed by the excellent tracings of 45/44 and 46/44 ratios. For organic carbon, carbonate-free samples were combusted at approximately 850°C to convert carbon to CO<sub>2</sub> gas. Water was removed with a slurry of dry ice and alcohol mixture. The CO<sub>2</sub> gas, which was then condensed using a liquid N<sub>2</sub> trap, was analyzed using a VG Optima isotope ratio mass spectrometer (IRMS). Results were reported in the conventional  $\delta$  value relative to the Peedee Belemnite (PDB) standard and expressed in per mil (‰). The analytical precision of the IRMS was better than  $\pm 0.06$ ‰. The errors in the isotopic measurements in duplicate sediment samples were variable and are shown in Table 2.

### 3. RESULTS AND DISCUSSION

Table 2 shows the results of calcium carbonate, organic carbon and their isotopic analyses of surface sediments from the East China Sea. It can be seen that carbonate concentrations are highly variable from 3.0 to 63.1 wt%, while organic carbon contents change from 0.1 to 1.44 wt%. It is well known that carbonate and organic carbon of sediments originate from calcareous organisms that survive dissolution/decomposition in the water column and/or after deposition. Preservation of organic matter in sediments also depends upon the redox conditions of environments in which the organic matter accumulates. For sediments in the marginal seas, carbonate and organic carbon contents are further controlled by the dilution of the land-derived detritus (Degens and Mopper, 1976; Suess, 1980). As a consequence, results of the highly variable carbonate and organic carbon concentrations measured in this study are consistent with the general characteristics of sediment deposited in the marginal sea regime.

However, as shown in Table 1 and Figure 2a, sediments of relatively high carbonate content are invariably found in the present-day water depths between 90-150 m, and the concentration tends to increase sharply toward the south. Furthermore, except for those in the north East China Sea, sediments of high carbonate contents are usually associated with low organic carbon contents (Figure 2b). They are mainly mixtures of well-sorted fine sands, shell fragments and gravel (Milliman *et al.*, 1985) and are readily distinguishable from sediments deposited outside this depth interval owing to the relatively low carbonate and high organic carbon contents of the latter (Figure 2). On the basis of sedimentation rate measurements and other sedimentary criteria, DeMaster *et al.* (1983) and Emery *et al.* (1971) reported that the area was characterized by non-deposition, indicative of a relic origin.

Table 2. Results of calcium carbonate, total organic carbon and their isotopic measurements of sediments in the East China Sea.

Sample No.	CaCO <sub>3</sub> ( wt % )	TOC ( wt % )	$\delta^{13}\text{C}_{\text{TOC}}$ ( ‰ )	$\delta^{13}\text{C}_{\text{carb}}$ ( ‰ )	$\delta^{18}\text{O}_{\text{carb}}$ ( ‰ )
1	8.0(7.4)	0.43(0.48)	-21.9	-0.6	-4.3
2	34.2	0.42	-22.1	-0.0	-6.1
3	63.1	0.10	-20.9	1.0	-6.2
4	7.9	0.14	-20.9	0.3	-0.9
5	27.7	0.18	-20.6(-21.3)	1.3	-3.8
6	36.7	0.10	-20.2	0.4	-1.9
7	49.9(49.6)	0.14(0.14)	-20.4	1.3(1.1)	-0.4(-0.9)
8	10.1	0.22	-21.3	1.2	-0.8
9	48.3	0.14	-20.4	1.0	-4.2
10	3.0	0.14	n.d.	0.5(1.8)	-1.9(-1.6)
11	8.1	0.15	-20.5	0.6	-1.7
12	5.5	0.15	-22.2(-22.2)	3.5	-5.4
13	19.3(19.9)	0.20(0.21)	-21.1(-21.0)	-0.8	-2.1
14	18.8	0.19	-21.4	0.5(0.6)	-1.2(-1.2)
15	22.6	0.26	-20.3	0.7	-2.6
16	8.3	0.32	-22.5	-0.2	-2.3
17	11.2	0.25	-22.9	-0.2(0.2)	-2.6(-2.1)
18	17.2	0.30	n.d.	0.5	-0.8
19	29.3	0.21	-22.3	-0.1	-0.8
20	18.7(18.5)	0.23(0.23)	-20.9	0.5	-1.5
21	5.7	0.21	-20.9	1.2	-1.1
22	37.0	0.29	-20.5	-0.7	-1.7
23	46.1(46.0)	0.24(0.26)	-20.8(-21.7)	0.4	-2.8
24	8.0	0.22	-20.9	-0.6	-1.7
25	8.5	0.29	-20.8(-20.8)	n.d.	n.d.
26	16.8	0.30	-20.8(-21.2)	-0.5(-0.1)	-1.5(-1.4)
27	28.2	0.40	-20.7	0.1	-1.2
28	28.0(28.2)	0.31(0.31)	-20.7(-20.7)	-0.6	-2.0
29	18.4	0.23	-21.1	0.2	-0.8
30	11.0	0.16	-20.8	-0.9	0.0
31	5.5	0.11	-20.3(-20.3)	0.2(0.2)	-0.2(-0.2)
32	8.4	0.16	-20.8	0.4(0.3)	-1.4(-1.5)
33	8.5(8.6)	0.19(0.19)	-21.8	-0.2	-1.4
34	9.3	0.26	-20.8(-20.6)	-0.1	-0.6
35	16.0	0.30	-21.6(-21.1)	-0.7	-2.8
36	16.4	0.35	-22.0(-21.3)	-0.1	-1.0
37	8.2	0.24	-21.9	0.0	-1.2
38	16.4	0.24	-21.2(-20.9)	0.1	-0.9
39	7.0	0.27	-22.0	-0.7	-2.4
40	8.7	0.47(0.47)	-20.8	-1.3	-3.5
41	n.d.	0.38	-21.3	n.d.	n.d.
42	8.5	0.38	-20.5(-21.3)	-0.3	-1.4
43	12.2	0.40	-21.2(-20.8)	-0.1	-1.5
44	13.3	0.32	-22.7	0.0	-0.6
45	14.1	0.36	-21.8	0.2	-1.8
46	8.0(7.7)	0.21(0.21)	-22.5(-21.4)	0.4	-0.7
47	16.5	0.28	-22.3	0.6	-0.9
48	32.6	0.31	-21.3	0.6	-1.2
49	16.5(16.3)	1.44(1.48)	-21.9	0.6(0.5)	-2.2(-1.6)
50	6.1	0.59	-21.4	-2.1(-2.2)	-3.1(-3.0)
51	4.2(4.1)	0.66(0.65)	n.d.	-2.0	-3.4
52	8.6	0.73	-21.7	-1.4	-3.2
53	10.4	0.80	n.d.	n.d.	n.d.
54	14.2	0.46	-20.5(-21.1)	n.d.	n.d.
55	16.2(16.4)	0.49(0.47)	-20.1(-20.8)	0.1	-1.2
56	10.4	0.36	-20.5(-20.8)	0.2	-1.4
57	4.2	0.59	n.d.	-0.0	-3.9
58	21.3	0.60	-21.4	n.d.	n.d.

n.d. : not determined

( ) : value of duplicate

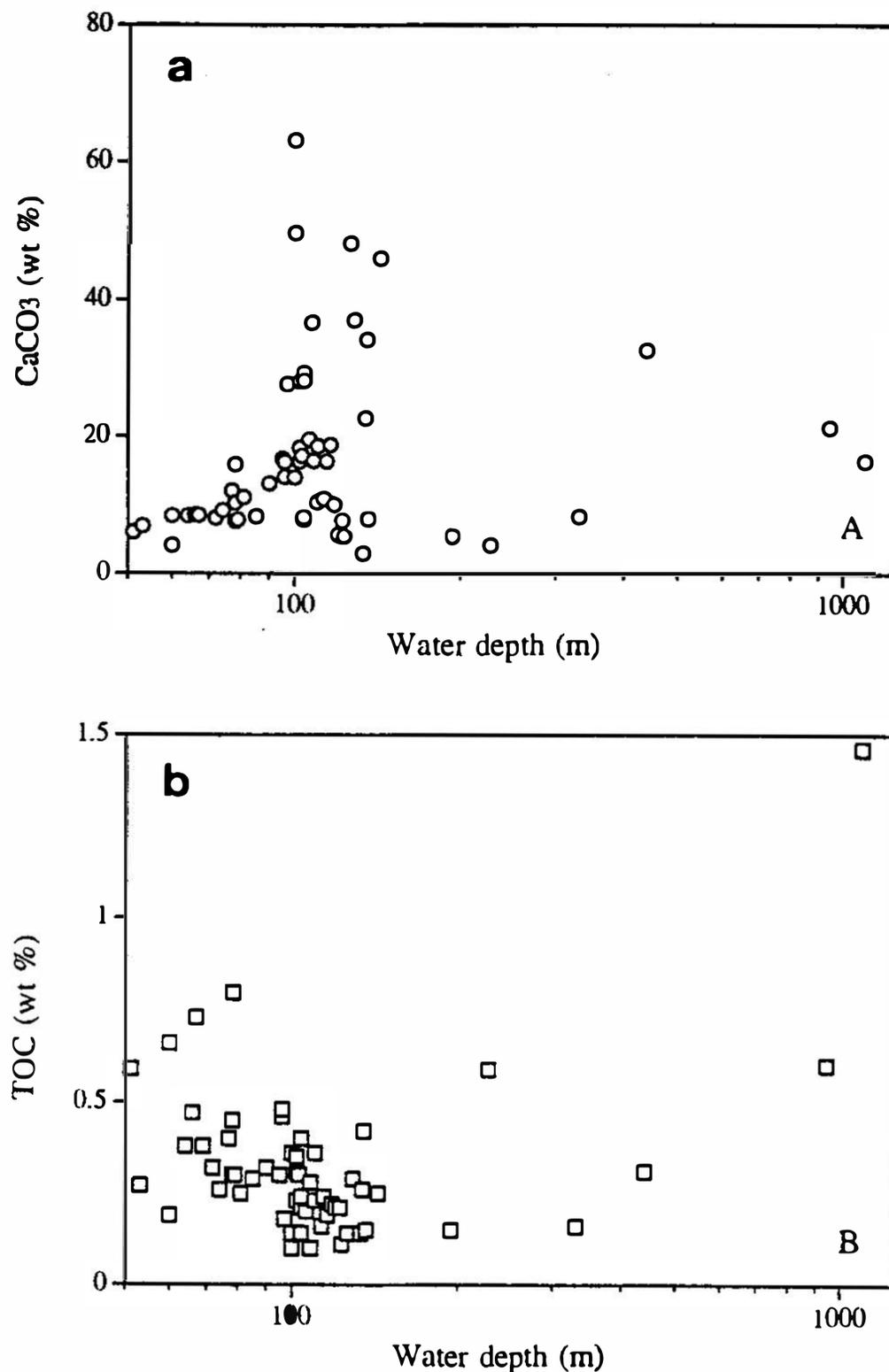


Fig. 2. Plots of calcium carbonate (a) and total organic carbon (b) concentrations vs. water depths in surface sediments of the East China Sea. Note that water depths are in the logarithmic scale.

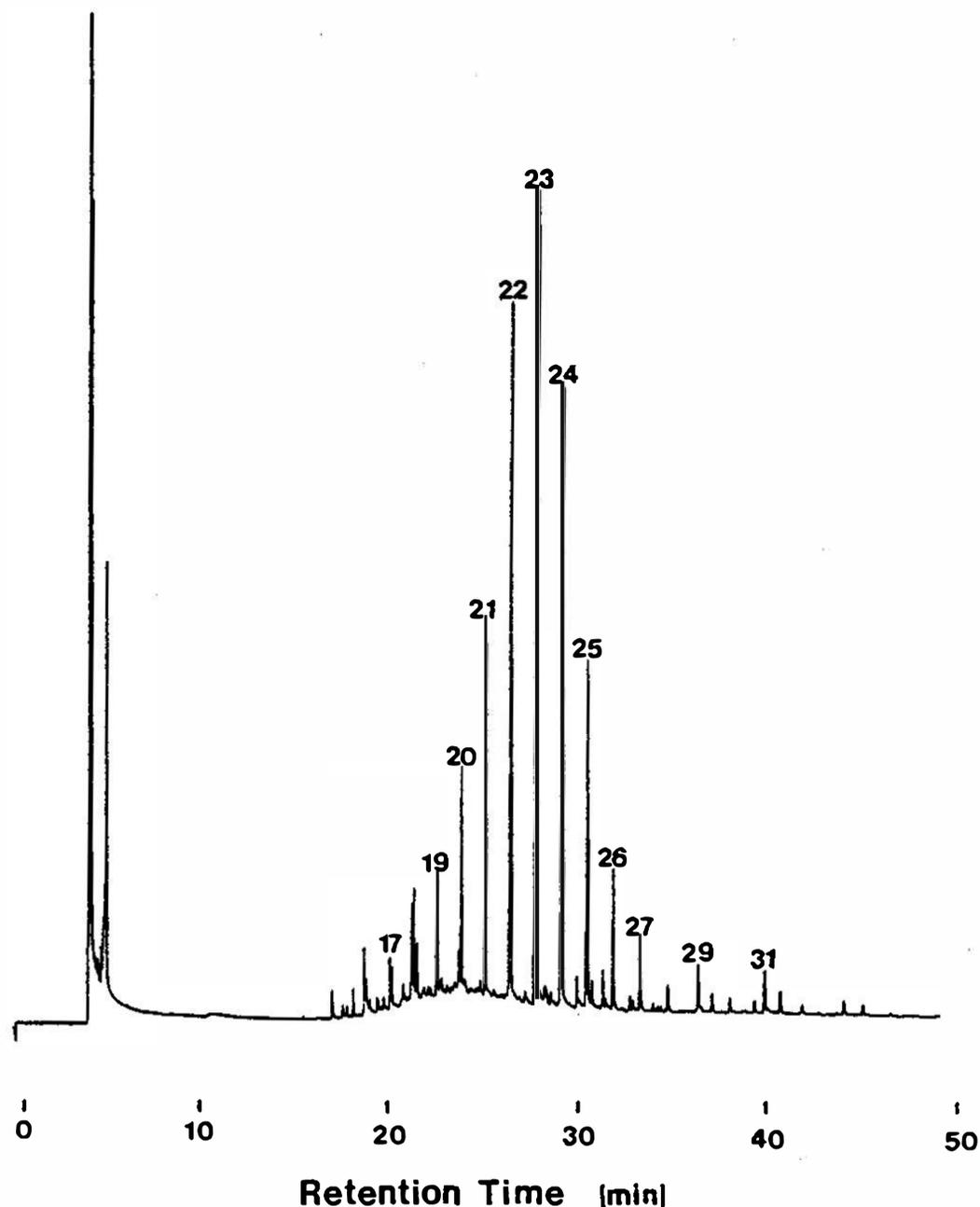
A close examination on sediment samples in this study also reveals that sediments of high carbonate contents are usually associated with abundant shell fragments. Accordingly, the coupling of high carbonate with low organic carbon concentrations in these sediments can be attributed to the selective removal of fine-grained sediments, which are known to enrich in organic carbon contents, during low stands of sea level. In other words, the sediments presently found between the water depths of 90-150 meters are those which have not been covered by recent deposition. Results from carbonate and organic carbon distribution revealed in this study, therefore, are consistent with episodes of non-deposition previously reported in other literature.

The  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  of carbonates in the surface sediments of the East China Sea vary respectively from  $-2.1$  to  $+1.3$ ‰ (excluding the questionable value of  $+3.5$ ‰) and from  $-6.2$  to  $+0.0$ ‰ (Table 2). Unlike the distribution of carbonate contents, no simple correlation of their isotopic compositions to water depths can be observed. Nonetheless, relatively light

values of  $\delta^{13}\text{C}$  are mostly found in the area of water depths less than 90 m, while those with very light  $\delta^{18}\text{O}$  of carbonates are invariably associated with sediments of relic origin (Table 2 and Figure 1). Furthermore, the majority of the  $\delta^{13}\text{C}$  of carbonates in sediments varies within a narrow range of  $2\text{‰}$ , while  $\delta^{18}\text{O}$  varies considerably over a range of  $6\text{‰}$  (see also Figure 5b). It is well known that the  $\delta^{18}\text{O}$  of biogenic carbonates is a function of the isotopic composition of water, in which organisms live, and its ambient temperatures in which the isotopic equilibrium is accomplished. Through the geologic time, sea water  $\delta^{18}\text{O}$  is further related to the global glaciation-interglaciation cycles. During the glacial time  $\delta^{18}\text{O}$  of sea water tends to become heavier due to the lock of light  $\delta^{18}\text{O}$  in the polar ice sheets, while during the interglacial time melting of the polar ice sheets and its subsequent release of the light  $\delta^{18}\text{O}$  water to the ocean decreases the  $\delta^{18}\text{O}$  of sea water. The highly variable  $\delta^{18}\text{O}$  measured in this study suggests that carbonates in the surface sediments of the East China Sea have experienced a wide range of temperature fluctuations, and it thus points to a relic origin as suggested previously.

$\delta^{13}\text{C}$  of organic carbon in these sediments varies from  $-22.9$  to  $-20.1\text{‰}$  (Table 2). Unlike the  $\delta^{13}\text{C}$  of carbonates which is mainly controlled by the  $\delta^{13}\text{C}$  of dissolved  $\text{CO}_2$  in sea water (Francis, 1980), the  $\delta^{13}\text{C}$  of organic carbon in marine sediments is further related to the source of carbon that has a diversity of origins and distinct carbon isotopic compositions. For instance, the  $\delta^{13}\text{C}$  of marine phytoplankton differs from that of terrestrial plants by approximately  $5\text{-}10\text{‰}$ , owing to the isotopic fractionation of carbon between atmospheric  $\text{CO}_2$  and dissolved bicarbonates (Faure, 1984). Although cautions need to be taken, the difference in carbon isotopic compositions of organic carbon has long been used widely to help distinguish the source of sediments in marginal sea basins (Sackett and Thompson, 1963; Hunt, 1970; Sackett, 1989; Jasper and Gagosian, 1989 and references therein). According to these authors, marine phytoplankton has a  $\delta^{13}\text{C}$  value of approximately  $-20\text{‰}$ , while C3-plants in lands have a characteristic  $\delta^{13}\text{C}$  value of  $-25\text{‰}$  (Craig, 1953; Degens, 1969). Values of  $\delta^{13}\text{C}$  in between are therefore indicative of a mixture of terrestrial and marine sources. As a result, the spatial variations in the  $\delta^{13}\text{C}$  of organic carbon in the surface sediments of the East China Sea continental shelf suggest changes in the inputs of terrestrial sources and subsequent mixing of the organic matter of marine origins.

Analysis of organic extracts from selected sediment samples by gas chromatography was then conducted to help identify types and sources of organic carbon in the sediments. Results show that organic carbon in the sediments from the East China Sea is chiefly composed of normal alkanes with carbon numbers from  $\text{C}_{15}$  to  $\text{C}_{31}$ . A typical gas chromatogram is shown in Figure 3, in which the normal alkanes are further shown to be dominant with carbon numbers from  $\text{C}_{21}$  to  $\text{C}_{25}$ . The predominance of these alkanes has always been identified in sediments off eastern Taiwan, yet their origins presently remains unknown. It is worthwhile, however, to note that the GC analysis of shale on land from the island of Taiwan often displays the same distribution patterns. It seems therefore that the sediments analyzed are ultimately transported from land. Figure 4 shows that the total concentrations of normal alkanes measured in sediments can vary up to ten-fold, yet show similar distribution patterns. Furthermore, the normal alkane concentrations in these sediments generally increase with the increasing organic carbon contents in these sediments ( $r=0.80$ ) except for samples 26, 27 and 38. It is interesting to point out that the latter three samples are located in area of sediments characteristic of relic origins (Figure 1), and the observed discrepancy may thus be attributed to the preferential degradation of biologically-fresh lipids in sediments upon deposition at low stands of sea level.



*Fig. 3.* A representative GC chromatogram (sample No. 57) showing typical normal alkane distributions of organic matter in surface sediments of the East China Sea.

Depending upon its origin, organic matter in sediments from the continental margin may consist of diverse types of normal alkanes, and the presence of various types of these normal alkanes in sediments can be used as an aid to infer the specific sources of organic contribution (Barnes *et al.*, 1984; de Leeuw, 1986; Philip and Lewis, 1987). For instance, esters,  $C_{37}$ - $C_{38}$  alkenones and  $C_{15}$ - $C_{19}$  alkanes are known to derive from lipids of marine organisms and are readily identifiable in the normal alkane fraction of organic extracts from recent marine sediments. Their presence in sediments, therefore, have been used to help delineate sediments of marine origins (Eglinton, 1969; Gelpi *et al.*, 1970; Blumer *et al.*, 1971; Sandstorm, 1988). Figures 3 and 4 reveal that the surface sediments in the East China Sea continental shelf are characterized by a similar distribution of normal alkanes with dominant carbon numbers from  $C_{21}$  to  $C_{25}$ , indicating a similar lipid source of these sediments. Nonetheless, normal alkanes in these sediments contain negligible esters and  $C_{37}$ - $C_{38}$  alkenones. They also lack the predominance of  $C_{15}$ - $C_{19}$  alkanes. Since these three lipid classes are usually observed in most recent marine sediments, their absence in the surface sediments of the East China Sea suggest that these sediments could not have been deposited in the region recently, instead they may have been deposited during low stands of sea level. Results from the GC analysis thus agree with previous observations and other geochemical and isotopic data revealed in this study as well.

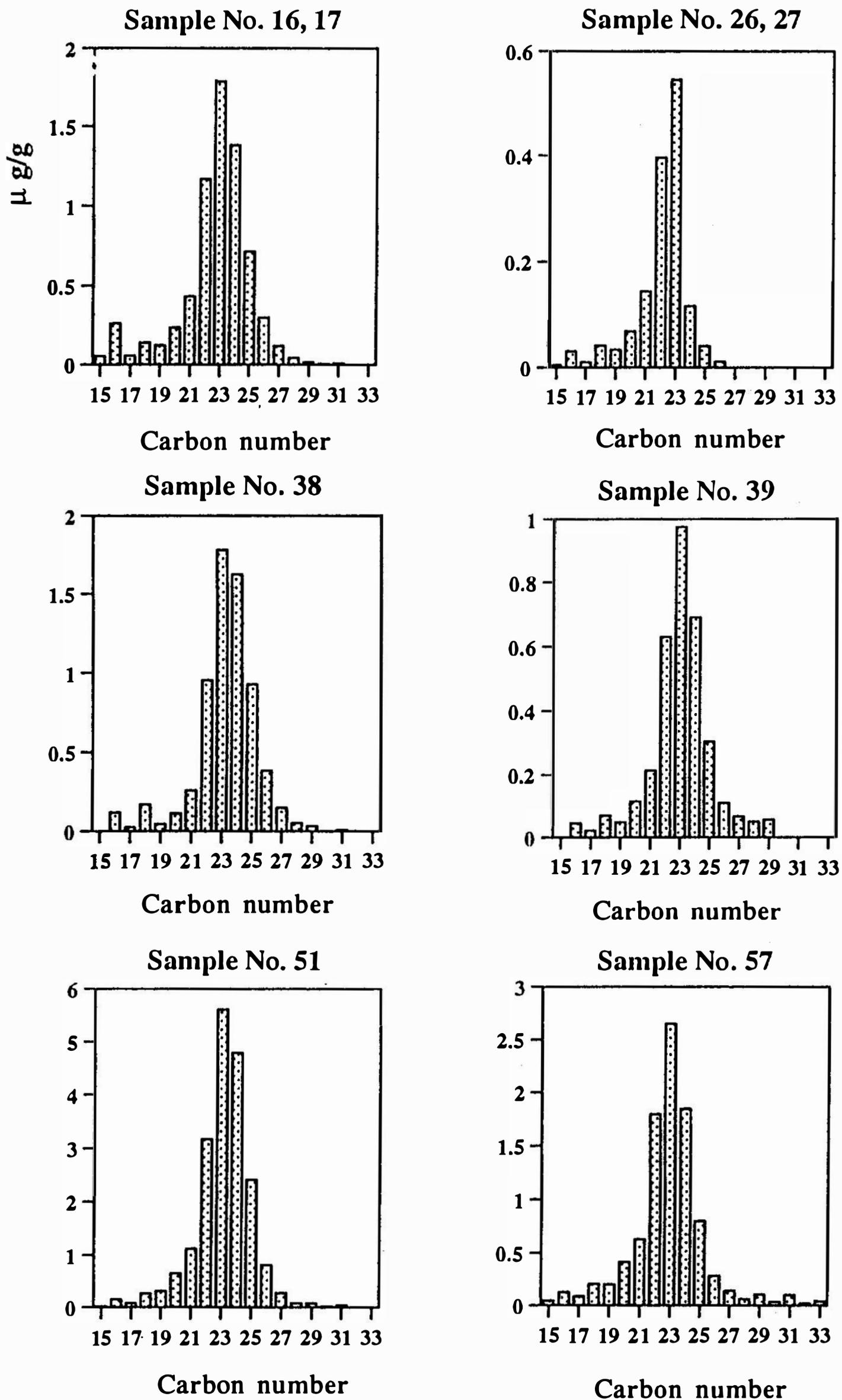


Fig. 4. Normal alkane concentrations, expressed as  $\mu$  g of different carbon compounds per gm of dry sediment, in surface sediments of the East China Sea. Note the different concentration scales used in each diagram.

#### 4. SUMMARY

In summary, with few exceptions, surface sediments in the continental margin of the East China Sea in general can be grouped into three major categories on the basis of their distinct geochemical and stable isotopic characteristics. Sediments of Type I (the open circles in Figure 5) are those characteristic of low carbonate and organic carbon contents having carbon and oxygen isotopic compositions of carbonates similar to those deposited in the present-day ocean. Type II mainly consists of sediments that have high organic carbon yet

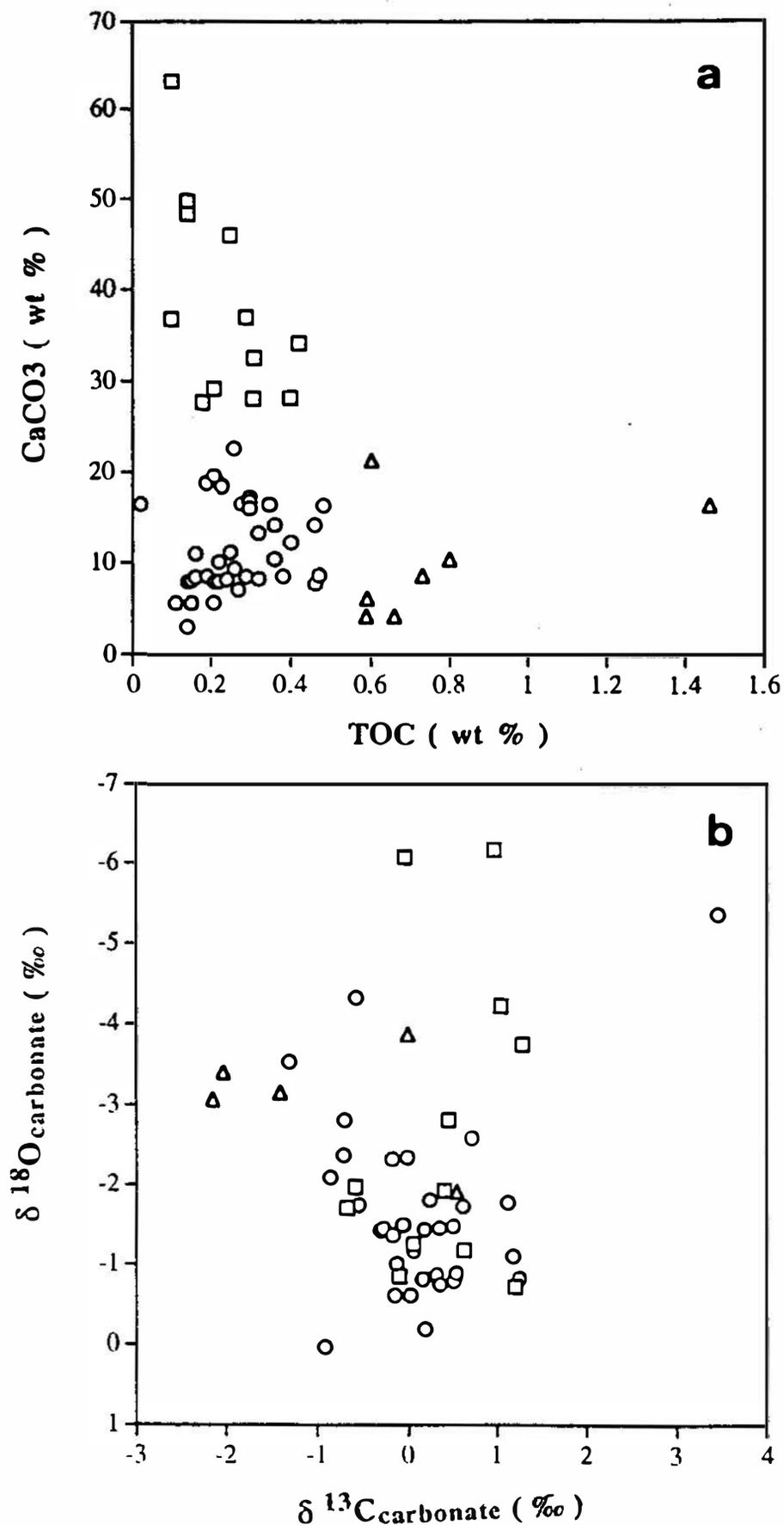


Fig. 5. Cross plots of calcium carbonate vs. total organic carbon contents (a) and oxygen vs. carbon isotopic compositions (b) of carbonates in surface sediments of the East China Sea. Different symbols stand for different sediment types (see text).

low carbonate concentrations (open triangles in Figure 5). This type of sediment usually shows a narrow range of  $\delta^{18}\text{O}$  (-3 to  $-4^{\circ}/_{\text{oo}}$ ) but a wide range of  $\delta^{13}\text{C}$  (-2 to 0). Sediments of Type III (open squares in Figure 5) represent those of high carbonate and low organic carbon contents and are observed in water depths between 90 and 150 m. The  $\delta^{18}\text{O}$  of carbonates in these sediments also exhibits a great variation from 0 to  $-6^{\circ}/_{\text{oo}}$  as compared to  $\delta^{13}\text{C}$  that falls in a narrow range of approximately  $2^{\circ}/_{\text{oo}}$ . Sediments of this type are believed to have been deposited during low stands of sea levels.

Results from the GC analysis of organic matter in selected sediments reveal that concentration of n-alkanes varies considerably up to ten-fold and generally increases with increasing organic content. Gas chromatograms show that these sediments have similar n-alkane distributions, suggesting that they have a similar source of lipids. Furthermore, the fact that the n-alkenes of organic matter in sediments are predominant with  $\text{C}_{21}$ - $\text{C}_{25}$  and that they lack esters and alkenones implies that they have not been deposited recently and may have been reworked and/or transported to the depositional sites.

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